Joint Precision Approach And Landing System (JPALS)

Technology Development (TD) Phase Accomplishments and Plans

Frank Allen, Sea Based JPALS, PMA-213 (NAVAIR)
Bob Norwood, Land Based JPALS, ARINC (ESC/GAL)

Outline

- Identify Technologies involved in solutions (architectures) being used or evaluated in TD
- Describe technology maturation process
- Demonstration results and plans for remainder of TD
- Status of technical specifications and integration guides

Purpose of Technical Development Phase

- Develop feasible architecture(s) and develop/document the JPALS performance requirements
- Develop and Validate Specifications for SDD
- Develop demonstration systems based on the candidate architecture(s) and show JPALS Technology Readiness through demonstration in an operationally relevant environment

Land-Based JPALS

Land-based TD Structure

Eric Lekberg, ESC/GAL, Hanscom AFB

Bob Norwood, Land-based System Engineer
Jack Wells, Land-based Supportability

Land-based Prime Contractor
ARINC Engineering Services (AES)

Honeywell Defense Systems
INS Aiding & Integration

Sierra Nevada Corporation (SNC) Stanford
Integrity & Continuity

Raytheon PGS
Anti-jam (AJ) Modeling & Simulation (M&S)

Navsys, Lockheed Martin Owego, Radix, Raytheon Systems Ltd., Comm. Sciences Corp.
AJ / Multipath Mitigation Systems

ITT Industries
Demonstration System

University of Colorado
Multipath M&S

TISI
Inertial Aiding

Rockwell Collins
Dual Frequency Algorithm

SNC
Installation Procedures

SNC, Raytheon PGS and NLS, and Honeywell
System Engineering Support

Availability Modeling Capability

- Availability Model (AM)
  - Enables assessment of availability under both nominal and jammed conditions
  - Representative error models for each component
  - Ranging source assumptions (constellation model)
  - Assessed against desired Guidance Quality (GQ)

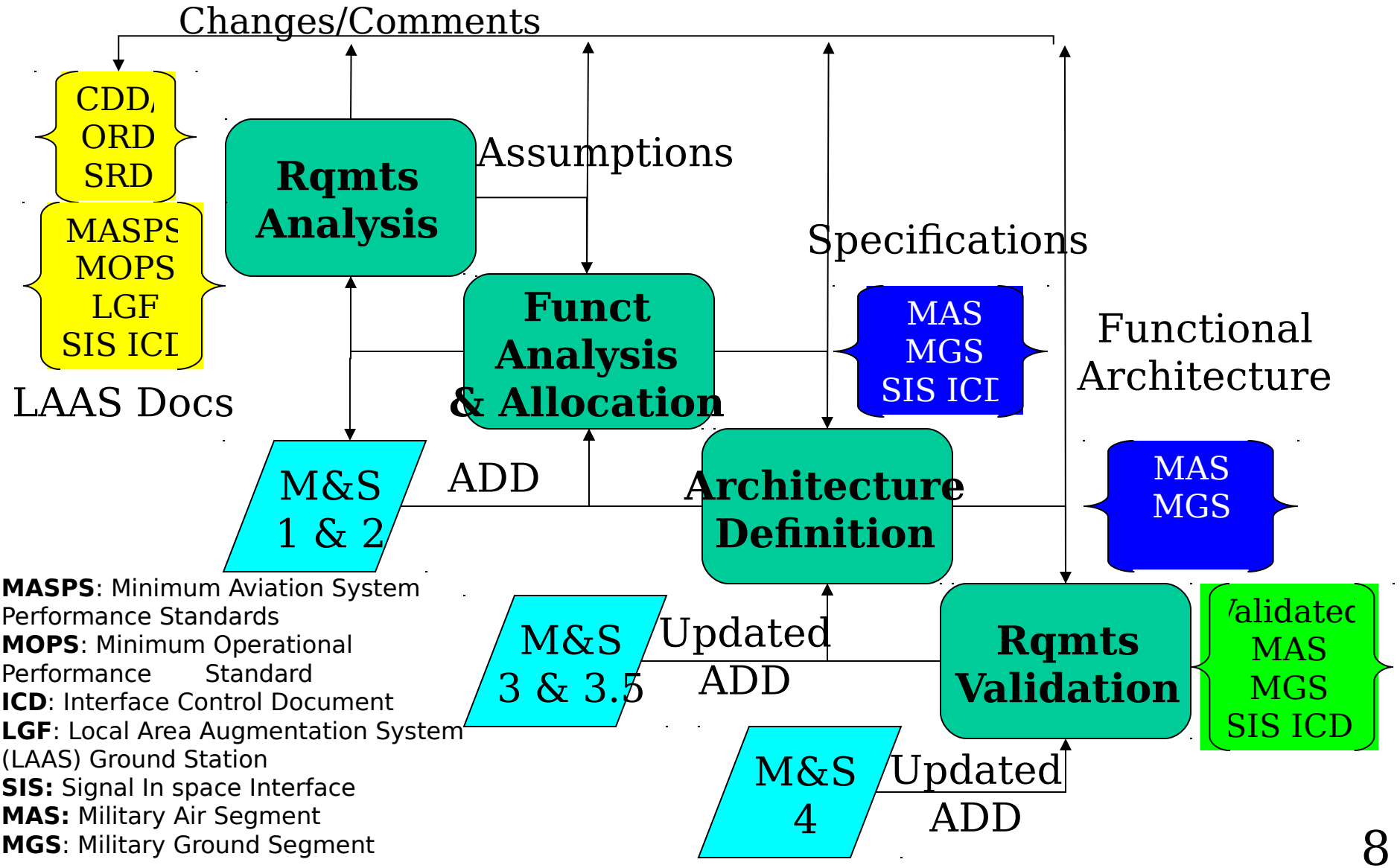
- Supported by:
  - Systems Engineering efforts refining error models, constellation assumptions and GQ requirements
  - Test and Evaluation efforts refining error models
  - External models of receiver and AJ performance
  - External tools for assessment of jamming threats

Performance Modeling Capability

- Performance Model (PM)
  - Simulates JPALS Land-Based ground and airborne processing
  - Offline capability for processing pre-existing data
  - Real time capability for operation within flight test systems

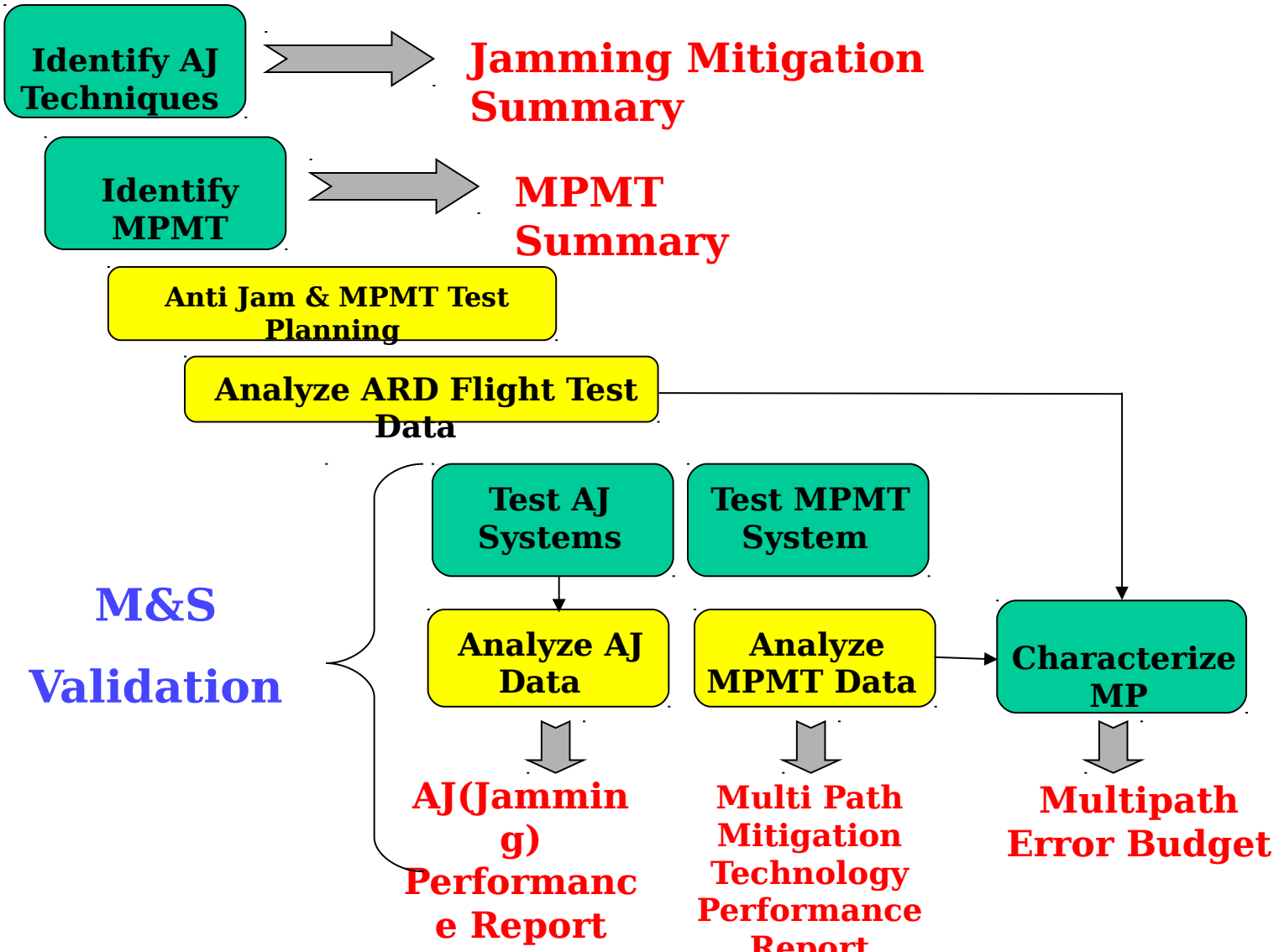
- Supported by:
  - Measurement model providing simulated GPS receiver data (both nominal and faulted)
  - Systems Engineering efforts refining processing and monitor algorithms
  - Test and Evaluation efforts which provide recorded data
  - Processed data from previous flight test efforts

Systems Engineering Approach



MASPS: Minimum Aviation System Performance Standards
MOPS: Minimum Operational Performance Standard
ICD: Interface Control Document
LGF: Local Area Augmentation System (LAAS) Ground Station
SIS: Signal In space Interface
MAS: Military Air Segment
MGS: Military Ground Segment

GPS Jamming & Multipath Mitigation



Land-Based Demonstration System

- Demonstration system
  - Airborne Executive Processor and Ground Executive Processor developed by ITT
  - Navigation software developed by ARINC
    - Re-host of Performance Model software
- Flight tests conducted 5-30 April at Holloman AFB
- Objectives
  - Overall objective
    - Aid in validating the assumptions made in updating MAS and MGS, validate the M&S assumptions, and validate the fidelity of the lab testing.
  - Detailed objectives
    - Demonstrate the accuracy of the system to perform at the appropriate Service Level (SL)
    - Evaluate the performance of various AJ technologies and their ability to support Cat 2 as part of the JPALS system
    - Demonstrate the dual frequency smoothing technique

JPALS Land-Based Overview

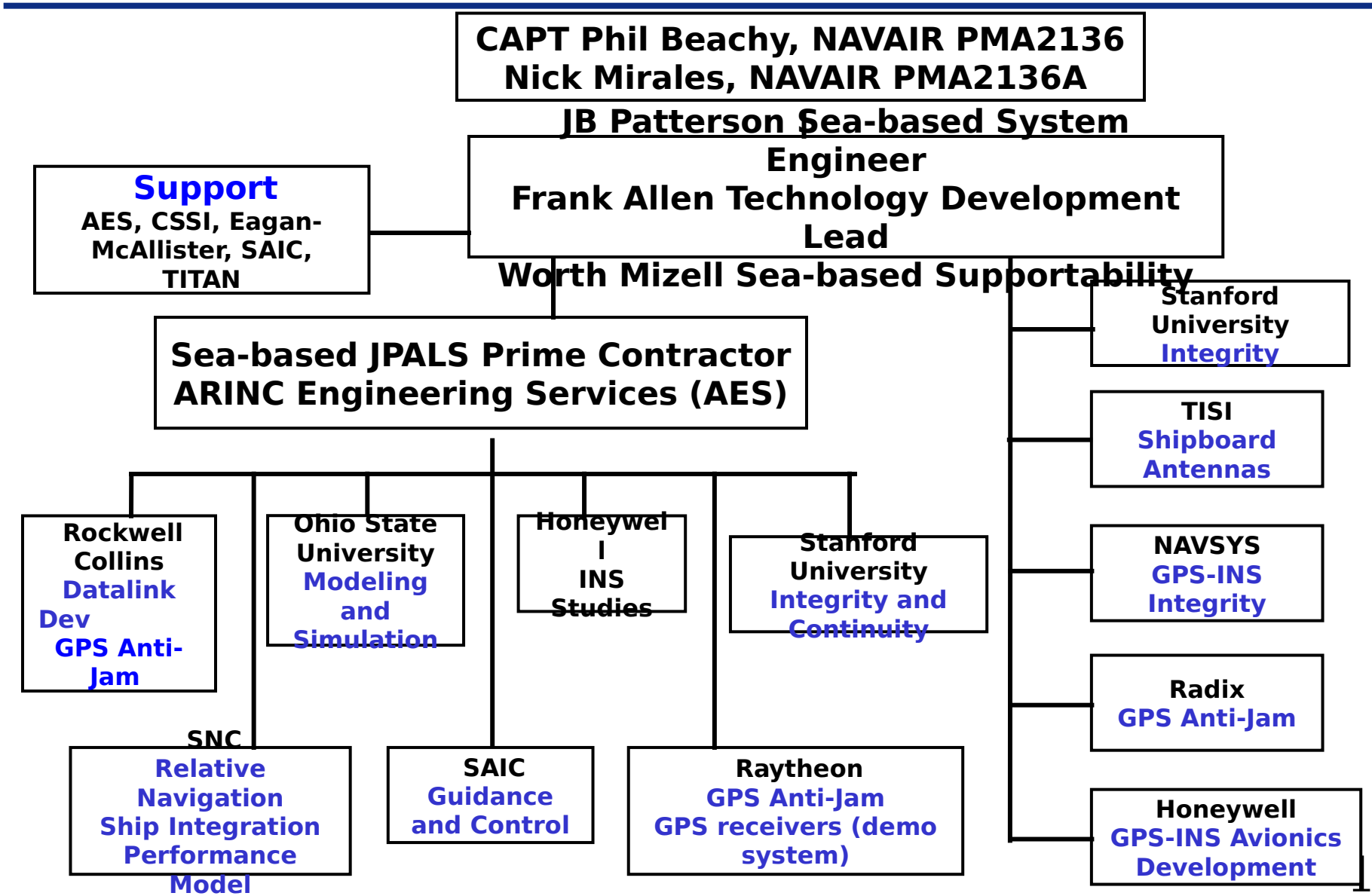
- ARINC (AES) Prime contract with Electronic Systems Center/Navigation and Landing Systems Program Office
  - Period of Performance 14 June 2002 – 28 July 2004
- Contract tasks
  - Develop and validated specifications for the JPALS Land Based GPS Military Airborne Segment and the Military Ground Segment to support Cat I and Cat II
    - Modeling and Simulation
      - Availability Model
      - Performance Model
    - Requirements and Architecture
    - Performance in Jamming and Multipath
    - Demonstration System Tests
  - Support Program Office ORD/CDD and SRD validation

JPALS Land-Based Schedule Status

- Completed
  - Development of Availability and Performance Models
  - Phase 1 and 2 of the Specification development
  - Phase 1 and 2 of the Functional Analysis
  - AJ lab tests and Multipath outdoor tests
  - Flight tests
- Major tasks yet to complete Analysis of Flight Test Data
  - Validation of Availability Model
  - Remaining Functional Analysis
  - Final update of MAS and MGS Specifications
    - Includes supporting documents
      - Systems Requirements Allocation
      - MAS Requirements Allocation and Functional Architecture
      - MGS Requirements Allocation and Functional Architecture

Sea-Based JPALS

Sea-based TD Team Structure



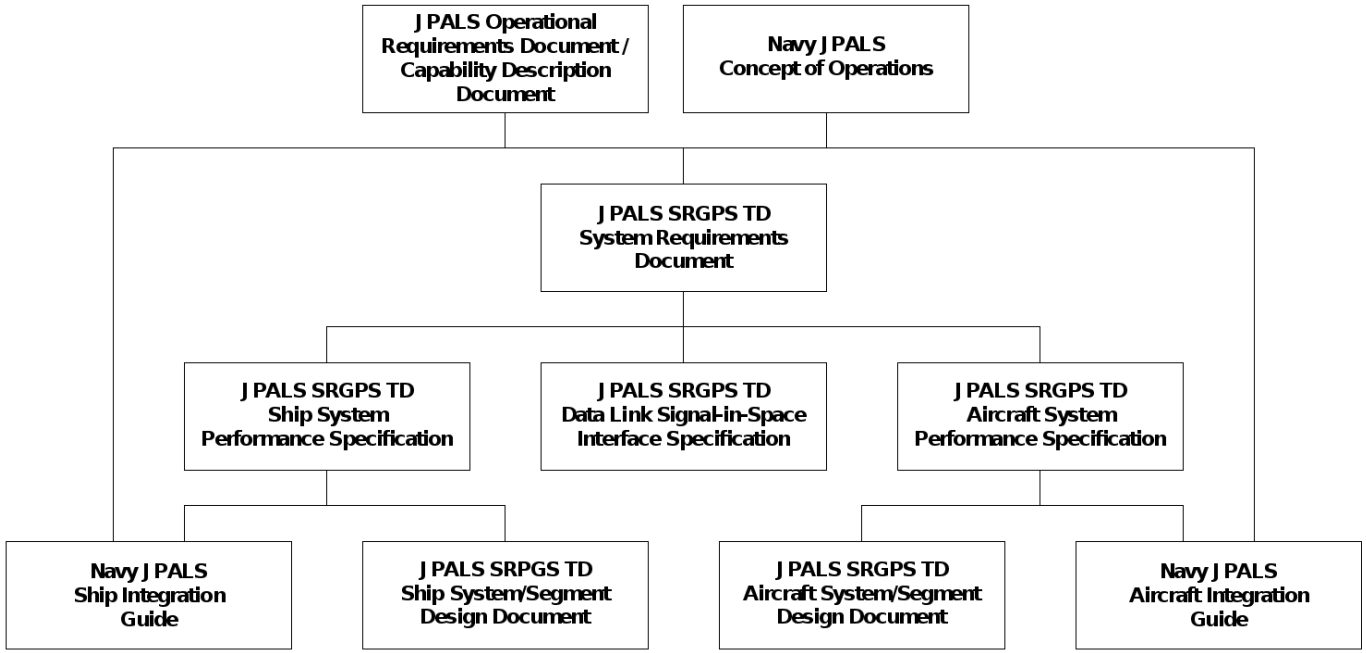
JPALS Sea-Based Overview

- Systems Engineering
  - System Integrity Maturation Panel
  - Requirements Allocation & Specification Development
  - Analysis
  - Aircraft Integration Guide Development
  - Shipboard Integration Guide Development
  - Market Research
- Technology Demonstration/Development
  - Build-Up to Shipboard Demonstration
  - Data Link Prototype Demonstration & Testing

Systems Engineering Task

- System Integrity Maturation Panel (SIMaP)
  - Purpose: Focus Ongoing Industry Research Activities to Benefit SRGPS Technology Development
  - Team members by Navy and ARINC
  - Steering Committee
    - Navy Team: PMA-213, Titan, Stanford University, TISI
    - ARINC Team: ARINC, Sierra Nevada Corp, University of Calgary, NAVSYS
    - Monthly Telecons

Systems Engineering Task (cont.)


J PALS Operational Requirements Document / Capability Description Document
Navy J PALS Concept of Operations
J PALS SRGPS TD System Requirements Document
J PALS SRGPS TD Ship System Performance Specification
J PALS SRGPS TD Data Link Signal-in-Space Interface Specification
J PALS SRGPS TD Aircraft System Performance Specification
Navy J PALS Ship Integration Guide
J PALS SRPGS TD Ship System/Segment Design Document
J PALS SRGPS TD Aircraft System/Segment Design Document
Navy J PALS Aircraft Integration Guide

- **Baseline 1.0 – October 03**
  - SRD, Aircraft, Ship and Data Link Specifications
- **Baseline 1.5 – June 04**
  - SRD, Aircraft, Ship and Data Link Specifications
- **Baseline 2.0 – January 05**
  - Aircraft and Ship Design Documents
  - Updates to Other Specifications
- **Baseline 3.0 – May 05**
  - Updates to All Documents and Specifications

Systems Engineering Task (cont.)

- Analysis
  - Purpose: Develop Models and Simulations to Aid in Requirements Allocation and Validation
  - Performance Model
    - Three Phase Development
      - Basic Model to Verify Functionality
      - Higher Fidelity Model to Evaluate Architectures and Jamming Response
      - Closed-loop Model with Aircraft Guidance and Control
  - Availability Model
    - Purpose: Develop Models and Simulations to Determine System Availability
    - Two Phase Development

Systems Engineering Task (cont.)

- **Aircraft Integration Requirements Document**
  - Purpose: AIG to define specific implementation details for each JPALS equipped platform
  - Approach: First release to define the document structure, subsequent releases to provide details
- **Ship Integration Requirements Document**
  - Purpose: SIG to define specific implementation details for each JPALS equipped platform
  - Approach: First release to define the document structure, subsequent releases to provide details

Systems Engineering Task (cont.)

- **Support Market Research**
  - Evaluate Viability of Technology to Support Maintenance Strategy
  - Reports Every Six Months Starting June 2004

- **Continuing Requirements Development**
  - Continue Requirements Research after Baseline 3.0 Release
  - Focus on Transition to Full Operational Capability
  - Report in September 2005

Technology Development Task

Shipboard Demonstration System

- Develop Demonstration System to Demonstrate Specific Aspects of System Performance
  - Precision Approach and Landing
  - Missed Approach and Bolter
  - Relative Navigation
- Naval Air Platform Integration Emulator (NAPIE) based
  - Re-host of Performance Model Software

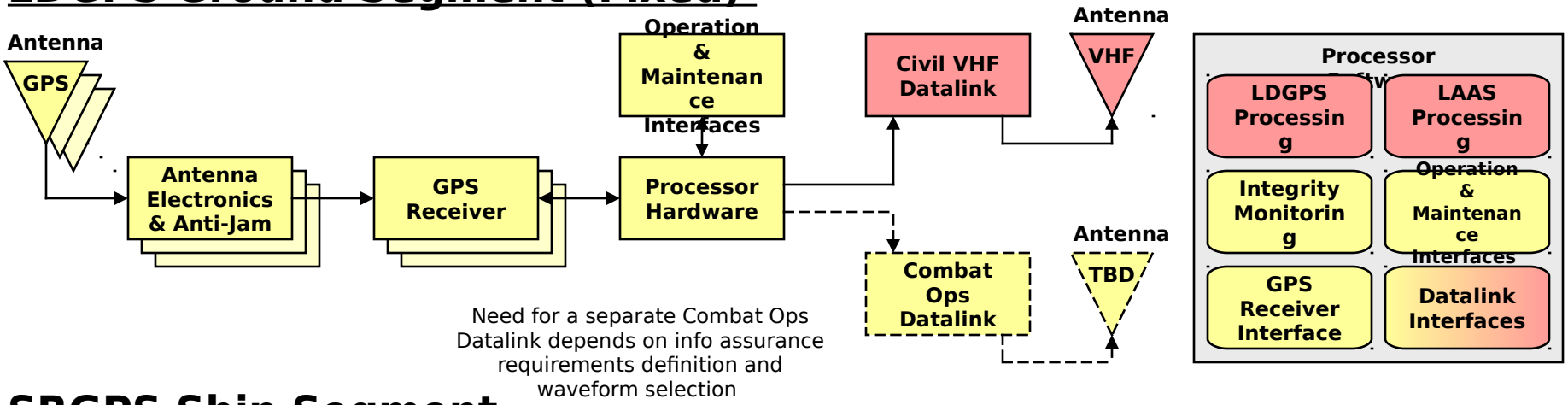
- Data Link Prototype Testing
  - Validate Waveform Specification
  - Integration with JTRS Waveform

JPALS Sea-Based Schedule Status

- **Completed**
  - Phase 1.0, 1.5 Specifications
  - Aircraft Integration Guide 1.0
- **Major Tasks yet to be completed**
  - Phase 2.0, 3.0 Specifications
    - Allocation of requirements between ship and air
  - Phase 2.0, 3.0 Aircraft Integration Guides
  - Phase 2.0, 3.0 Ship Integration Guides
  - Requirements Validation

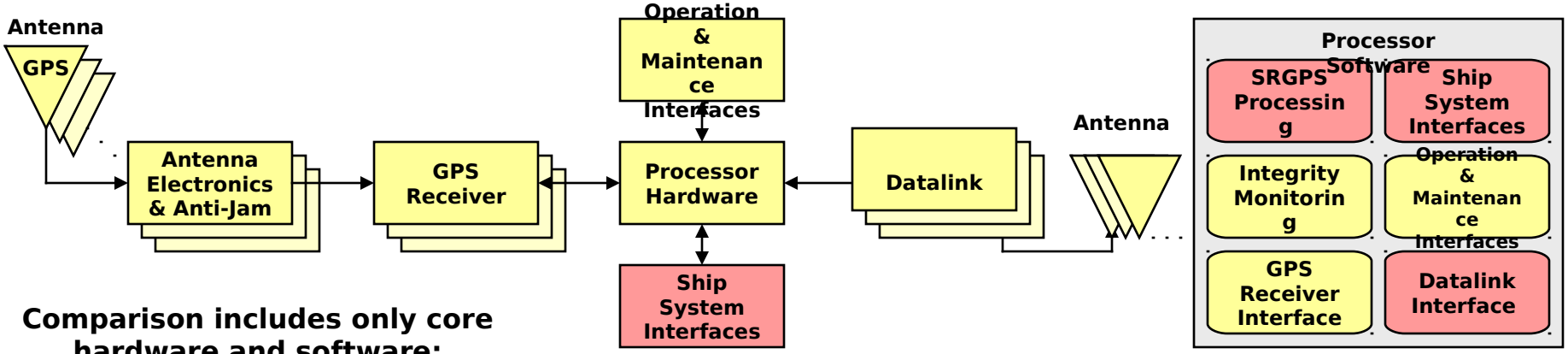
JPALS Ground/Ship Segment Architectures

LDGPS Ground Segment (Fixed)



Need for a separate Combat Ops Datalink depends on info assurance requirements definition and waveform selection

SRGPS Ship Segment

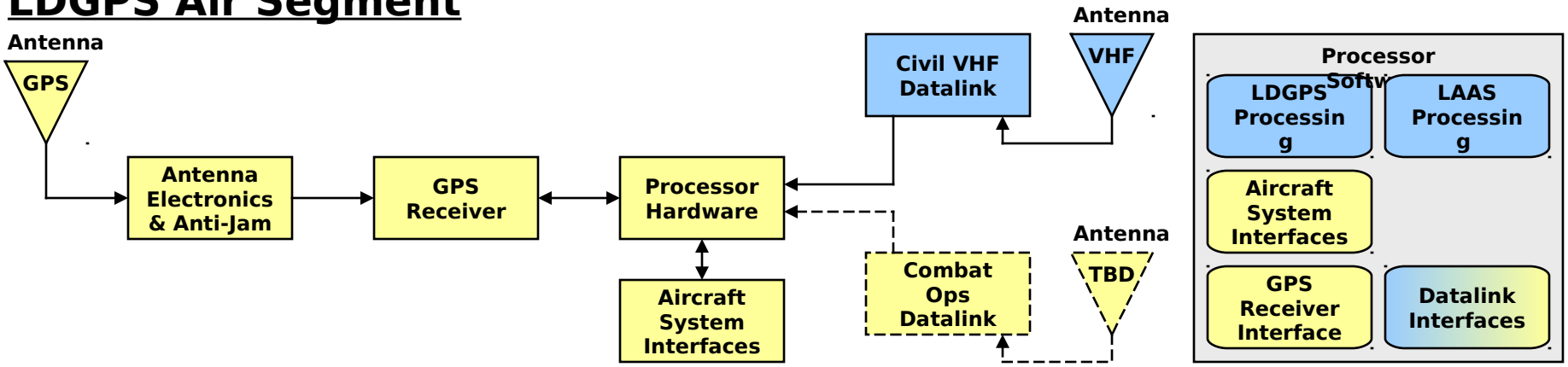


Comparison includes only core hardware and software; packaging will likely be different for each system

Common | Potential Commonality | Unique

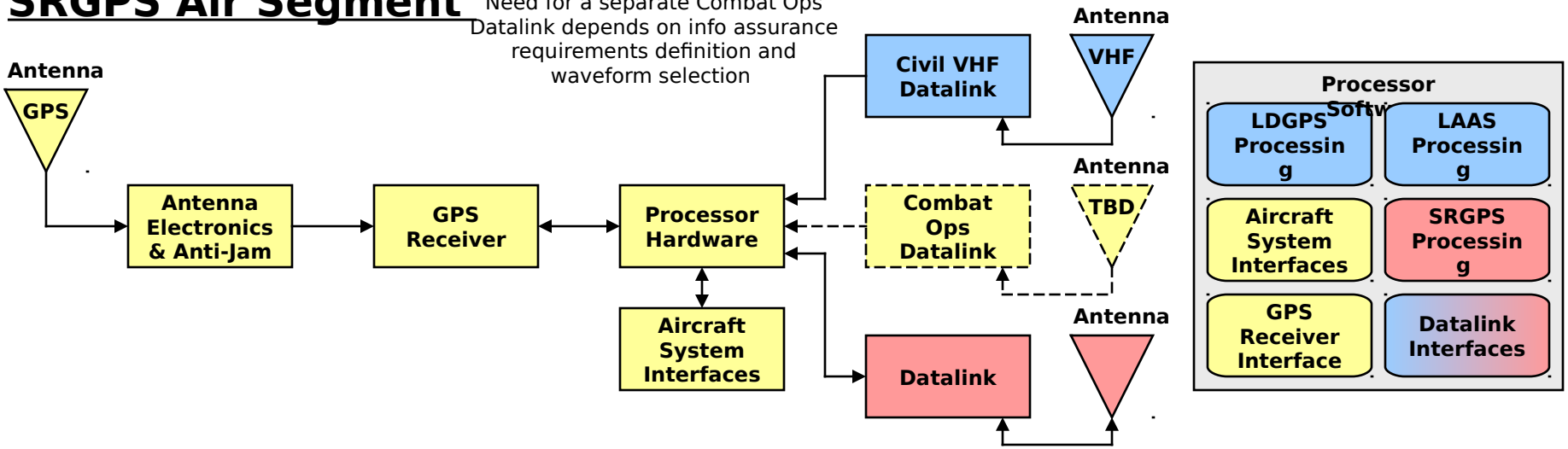
JPALS Air Segment Architectures

LDGPS Air Segment



SRGPS Air Segment

Need for a separate Combat Ops Datalink depends on info assurance requirements definition and waveform selection



Common | Potential Commonality | Unique

JPALS TD Accomplishments

- Conducted shipboard test of SRGPS aboard the USS Roosevelt (CVN 71) accomplishing 10 fully auto-coupled landings in Apr 01.
- Completed 276 approaches at Holloman AFB, NM during Jul-Aug 01. 154 in clear air, 122 in jamming.
- Flew LAAS avionics (FedEx 727) against the JPALS ground station to perform 10 auto-coupled landings (Aug 01).
- Pegasus X-47A Naval UCAV demonstrator first flight in Feb 03 achieved 4 inch GPS error on landing

JPALS TD Recent Accomplishments

- **AJ candidate testing at AFRL Antenna Wave-front Simulator**
- **Additional AJ testing at Holloman AFB included:**
  - **191 Approaches (121 jammed)**
- **At sea data collection on USS Truman**
- **Supported Vectored thrust Aircraft Advanced flight Control (VAAC) TIM in UK and shipboard testing (QinetiQ)**
- **Data undergoing extensive analysis**

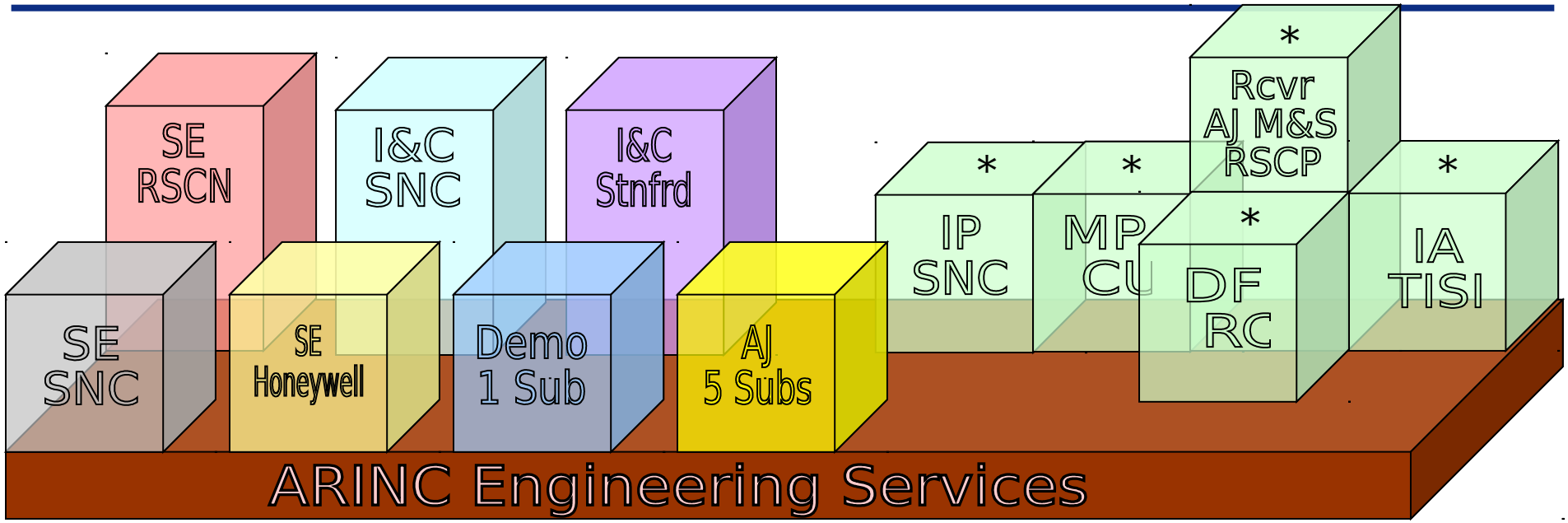
AFRL WFS

Truman Data Collection Trip

- Several Sea based Experiments Involved
- New 24 Channel Selective Availability Anti Spoof Module (SAASM) Receiver (4)
- Multiple Shipboard Receiver Data Collection
- Antenna Flexure Test
- Dynamic Beam Steering aboard ship
- RF Environment Recording
- 11 GPS Receivers aboard ship (~ 6 TB of data collected)

Back Up

Fitting it all together



- AJ ⇒ Anti-Jam
- DF ⇒ Dual Frequency
- Demo ⇒ Demonstration System
- IA ⇒ Inertial Aiding
- I&C ⇒ Integrity & Continuity
- IP ⇒ Installation Procedures
- MP ⇒ Multipath
- SE ⇒ Systems Engineering
- Rcvr/AJ M&S ⇒ Receiver/AJ Modeling & Simulation

- CU ⇒ University of Colorado
- RC ⇒ Rockwell Collins
- RSCN ⇒ Raytheon NLS
- RSCP ⇒ Raytheon PGM
- SNC ⇒ Sierra Nevada Corp
- Stnfrd ⇒ Stanford University
- TISI ⇒ Tracking & Imaging Systems, Inc.

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AES TD Land-Based Subcontractors

- **Sierra Nevada Corporation**
  - Integrity and Continuity, Systems Engineering Support, Installation Procedures
- **Stanford University**
  - Integrity and Continuity
- **University of Colorado**
  - Multipath
- **Rockwell Collins**
  - Dual Frequency Smoothing algorithms and analysis
  - AJ (MIDAS)
- **TISI** – INS Aiding
- **ITT** – Demonstration System Executive and Hardware
- **Raytheon PGS** – AJ Model
- **Raytheon Systems Limited, Rockwell, Navsys, Radix, Lockheed Martin** – AJ systems
- **Communications Sciences Corporation** –Multipath Mitigation Technique
- **Honeywell and Raytheon NLS** – Systems Engineering, review of spec's

Sierra Nevada Corporation

- Integrity and Continuity Analyses
  - Integrity and Continuity Allocations
  - Integrity and Continuity Algorithms
- Installation Procedures
  - Pre-mission Planning
  - Deployment
  - Site Certification/Commissioning
- Systems Engineering Support to AES

Stanford University

- Integrity and Continuity Allocations
  - Define Threat Models
  - Assess Integrity and Continuity Allocations
  - Optimize and Refine LDGPS Candidate Architectures
  - Define and Simulate LDGPS Candidate Architectures
- Ground and Airborne Algorithm Development
  - Find VPL and HPL to bound NSE
  - Develop algorithms
  - Test to validate algorithms and architecture

University of Colorado

- Modeling and Simulation
  - Basic multipath model
    - Include antenna environment model (Ohio State University scattering code)
    - Incorporate Anti-Jam (AJ) receiver model
  - Analyze expected multipath error based on simulated data
  - Testing and test data analysis
    - Develop test procedures for evaluation of AJ receivers for multipath
    - Characterize multipath errors in existing JPALS Architecture and Requirements Definition (ARD) data
    - Analyze AJ receiver test data (from phase 1 and 2 lab/outdoor tests at AFRL)
  - Performance evaluation
    - Compute error budget for mulitpath under range of jamming scenarios tested
    - Evaluate airborne multipath
  - Summary and recommendations

Rockwell Collins

- Dual Frequency Smoothing (DFS) Error Modeling
  - Derive models for post-detection signal-to-noise and multipath error
- DFS Accuracy Evaluation
  - Compare DFS DGPS and LAAS DGPS pseudorange accuracy under varying environmental conditions
- Modeling and Simulation Support
  - Evaluate potential improvements using DFS DGPS
- Digital Beam Forming Performance Evaluation
  - Develop error models for availability evaluations
- DFS LDGPS Flight Test Data Evaluation
  - Evaluate DFS LDGPS implementations with ARINC supplied dual frequency flight test and truth data

Systems Engineering Task (cont.)

- Requirements Allocation and Specification Development
  - Purpose: Allocate ORD/CDD and CONOPS Requirements to Ship, Aircraft, and Data Link Systems, and Validate Allocations
    - Validated Specifications are Basis for SDD
  - Focused on 2010-2011 JPALS Implementation
  - Approach: Phased Release of Requirements Specifications and Design Documents
    - Each Baseline Release is a Consistent Set of Documentation Presenting Current State of Allocations
    - Four Baseline Releases **(see next chart)**

AES Team

- Primary Subcontractors
  - Sierra Nevada Corporation
    - SIMaP, Requirements, Specifications, Availability Model, Demonstration
  - Rockwell Collins
    - Requirements, Specifications, Data Link Prototype Development and Testing
- Other Subcontractors
  - CRS – Performance Model (PM) Executive
  - SAIC – Guidance and Control
  - Logan Scott Consulting – Anti-jam Hardware Models (???)
  - Raytheon PGS – GPS Receivers and Data Link Support
  - Ohio State University – Multipath Analysis – Performance of STAP/SFAP AJ Systems
  - University of Calgary – GPS/INS, Ambiguity Resolution
  - University of Colorado – Multipath Analysis
  - ITT –Satellite Constellation and Ionospheric models for PM (???)
  - Raytheon NLS – Data Link support, review of spec's

Sierra Nevada Corporation

- Task Description
  - Requirements Allocation and Specification Development
    - Conduct Trade Studies and Analysis to Support Recommendations to Resolve TBRs and Allocate Requirements
    - Focus on SRD and Ship Performance Spec
    - Support work on DL SIS Spec and message/data packet content
  - Analysis
    - Input to Availability Definitions/Documentation
    - Develop Availability Model
    - Analyze Data from Ship Trips
  - Technology Development
    - Develop Relative Navigation Software / ADD
    - Aid in Demonstration Requirements Development and Design

- **Task Description**
  - Upgrade Multipath Measurement Error Model to Include Effect of Code-Tracking Errors
  - Develop Environmental Models for Shipboard Antennas
  - Analyze Expected Multipath Errors from Simulated Data
  - Develop Candidate Approaches for Carrier Phase Multipath Analysis
  - Develop Test Plans/Procedures for Evaluating Shipboard Code and Carrier Phase Multipath Mitigation effectiveness

- **Task Description**
  - Ambiguity Resolution
  - Cycle Slip Detection and Repair
  - Float-Ambiguity Filter Performance
  - Software Measurement Simulation

Honeywell INS Task Summary

- Compare the following from the navigation solutions:
  - the three dimensional position covariance of a weighted least squares navigation solution
  - the three dimensional position covariance from a tightly coupled GPS/ inertial integrated Kalman filter navigation solution
  - the true navigation position error
- Investigate the advantages of aiding the GPS tracking loops (code and carrier loops) with inertial data
- Evaluate degraded performance of a tightly coupled GPS/inertial navigation solution, e.g., less than four satellites in track
- Compare tightly coupled GPS/inertial navigation performance using differential corrections with and without the ionospheric delay
- Investigate the performance of an ultra-tightly coupled GPS/ inertial system (optional)